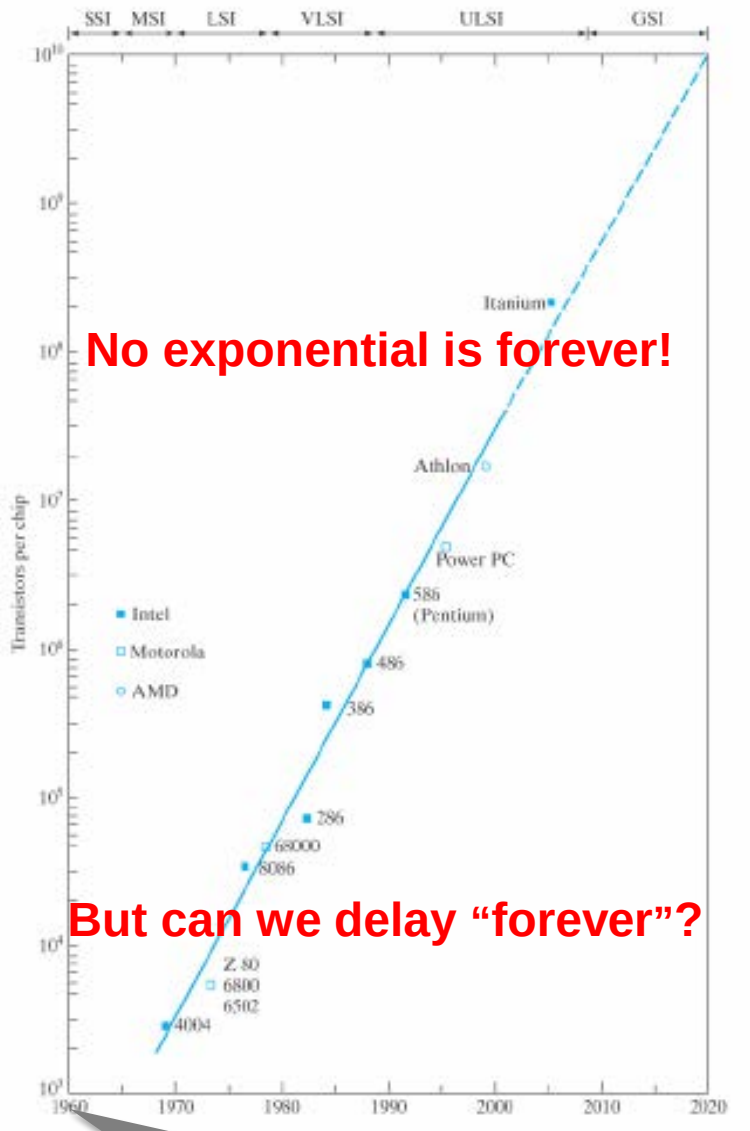
# Microelectronics: The Beginning of the End or the End of the Beginning?

- Texas GSP 1.5T$ (top 12 in world)
- Economy transition from resource to tech-based post WWII
- Information technology
- Green energy

**Sanjay K. Banerjee**
**Director, Microelectronics Research Center**
**Univ. of Texas at Austin**

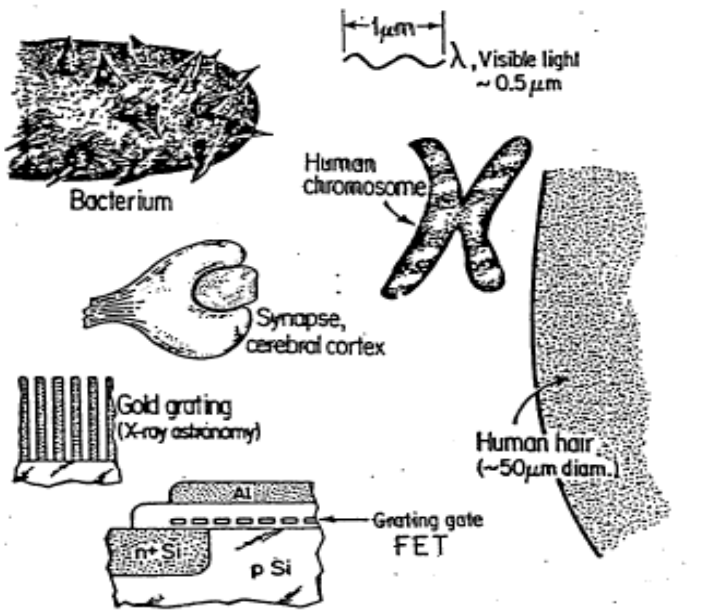
# Moore's Law

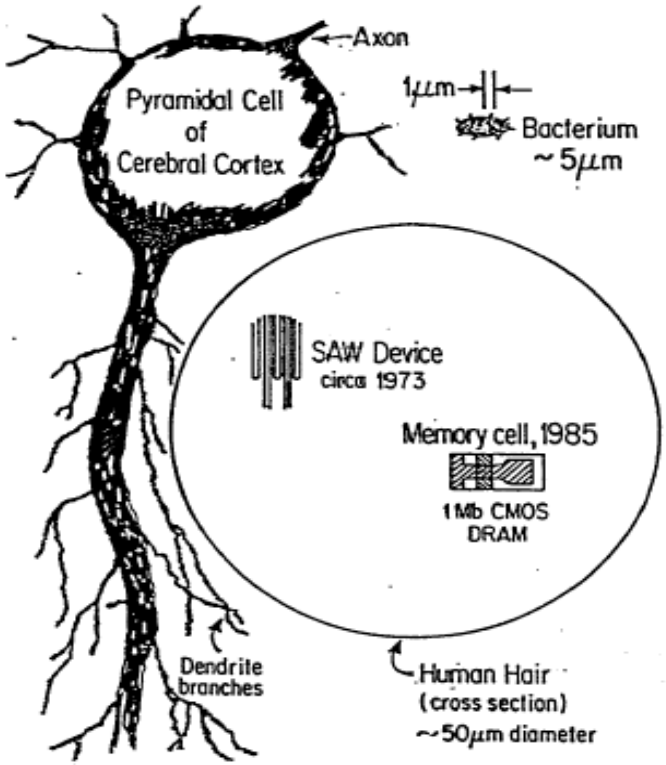



**No exponential is forever!**

**But can we delay "forever"?**

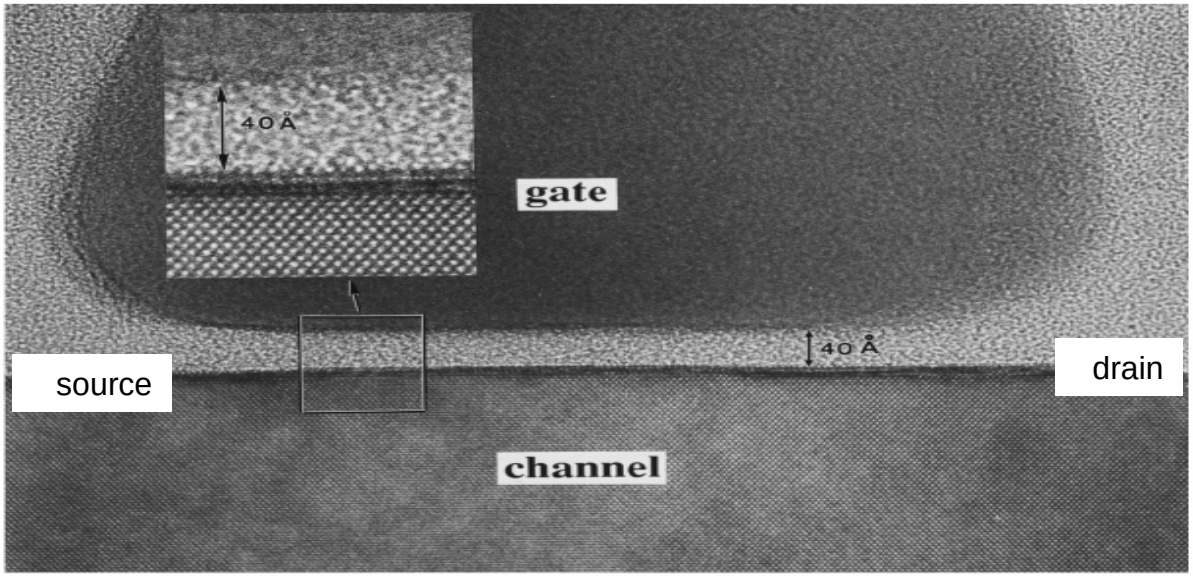
Invention of the IC by Nobel Laureate Jack Kilby of TI in 1958



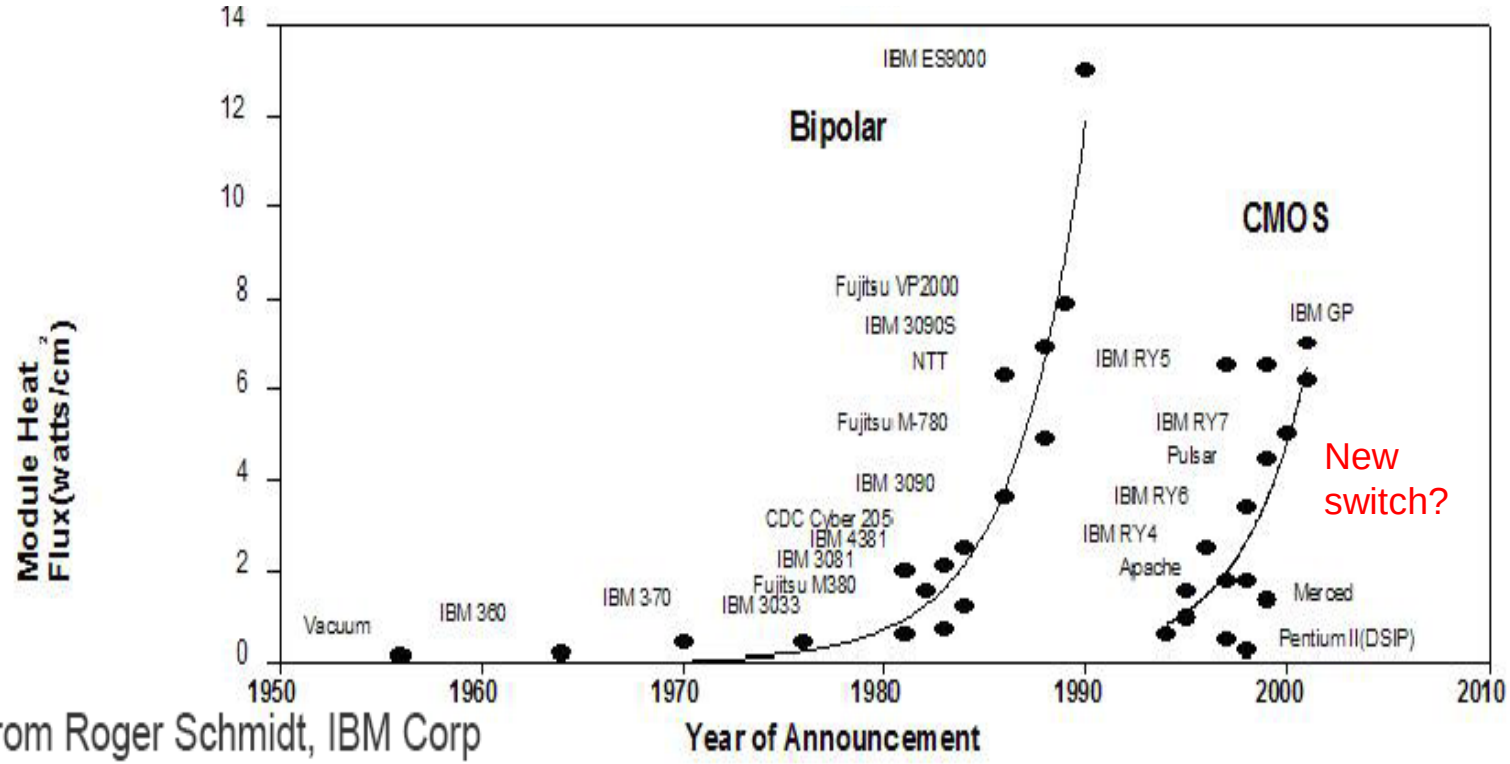



# Societal Impact

- The $300 billion IC industry drives a $1 trillion electronics business, and has been the lifeblood of the Information Age for the past 50 years.
- Average person owns over a 100 billion transistors.
- 100,000 transistors would fit across, and cost less than a single grain of rice.



# The Other Energy Crisis!




From Roger Schmidt, IBM Corp

# Opportunities for Transformation

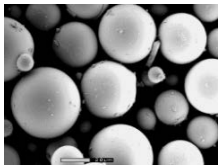
## Things Natural

Dust mite

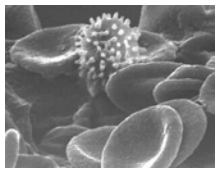
200 μm

Human hair
~ 60-120
μm wide

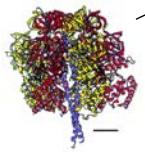
Ant
~ 5 mm



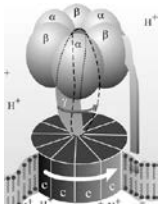
Fly ash
~ 10-20 μm



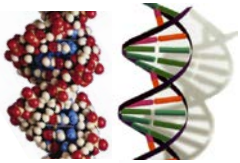
Red blood cells
with white cell
~ 2-5 μm



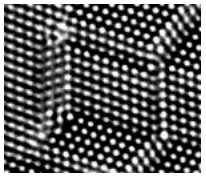
~10 nm
diameter



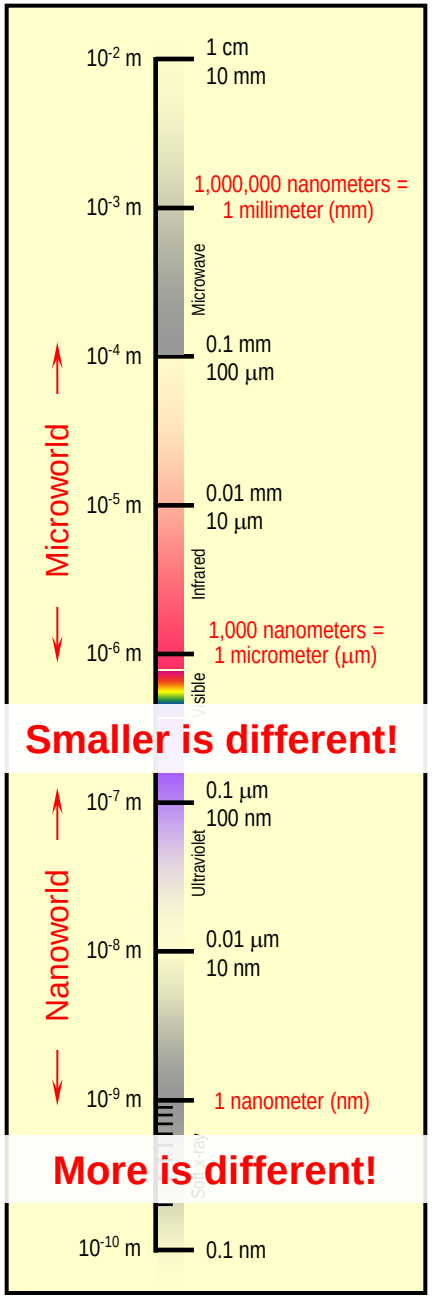
ATP
synthase



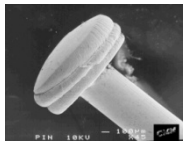
DNA ~2-1/2 nm diameter



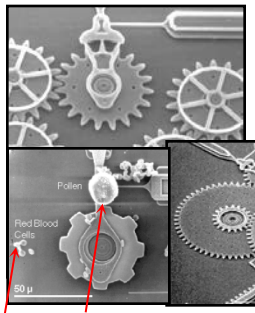
Atoms of silicon
spacing ~tenths
of nm




## Things Manmade

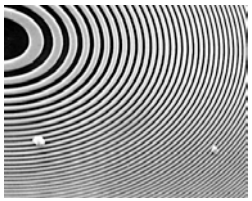


Head of a pin
1-2 mm

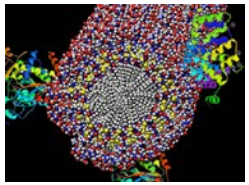



MicroElectroMechanical (MEMS) devices
10 -100 μm wide

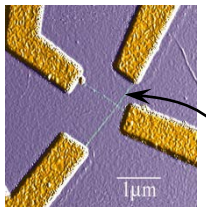
Pollen grain
Red blood cells



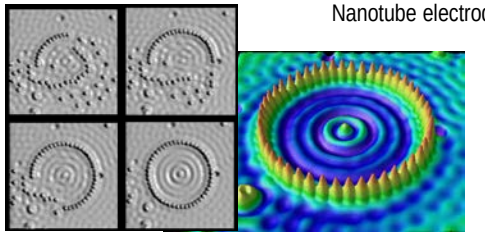
Zone plate x-ray "lens"
Outer ring spacing ~35 nm



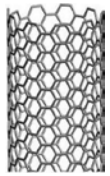
Self-assembled,
Nature-inspired structure
Many 10s of nm



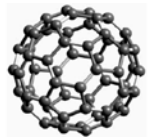

Nanotube electrode



Quantum corral of 48 iron atoms on copper surface
positioned one at a time with an STM tip
Corral diameter 14 nm



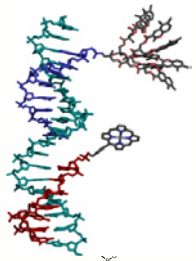
Carbon nanotube
~1.3 nm diameter



Carbon
buckyball

~1 nm
diameter

### The Challenge



*Fabricate and combine nanoscale building blocks to make useful devices, e.g., a photosynthetic reaction center with integral semiconductor storage.*

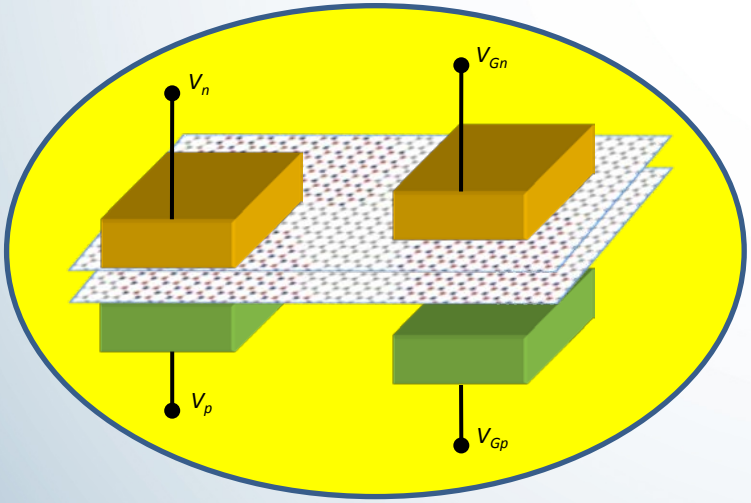
Office of Basic Energy Sciences
Office of Science, U.S. DOE
Version 10-07-03, pmd

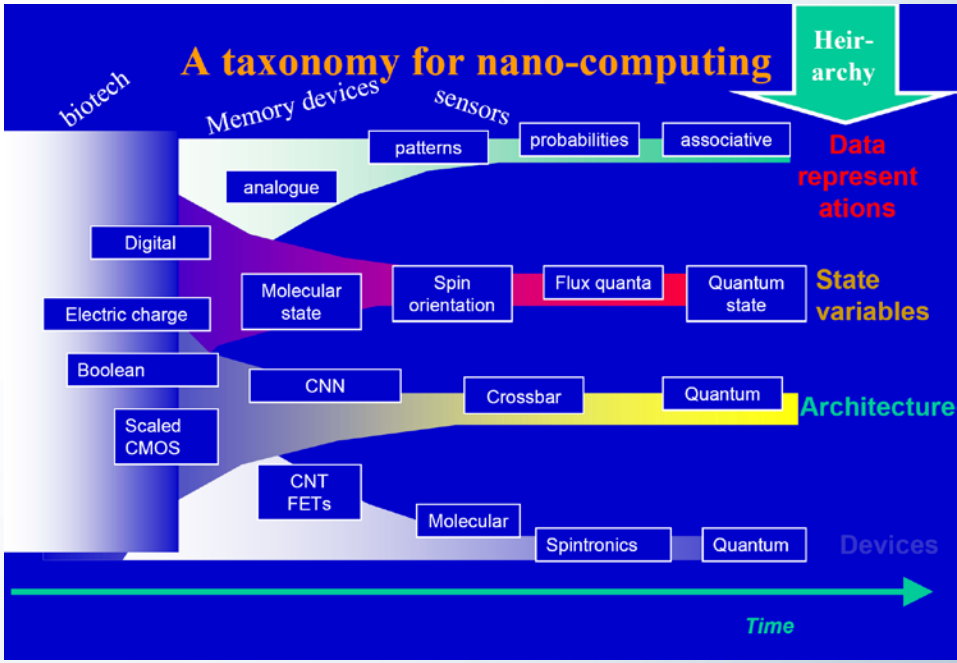
# Strategic Paths to Innovation

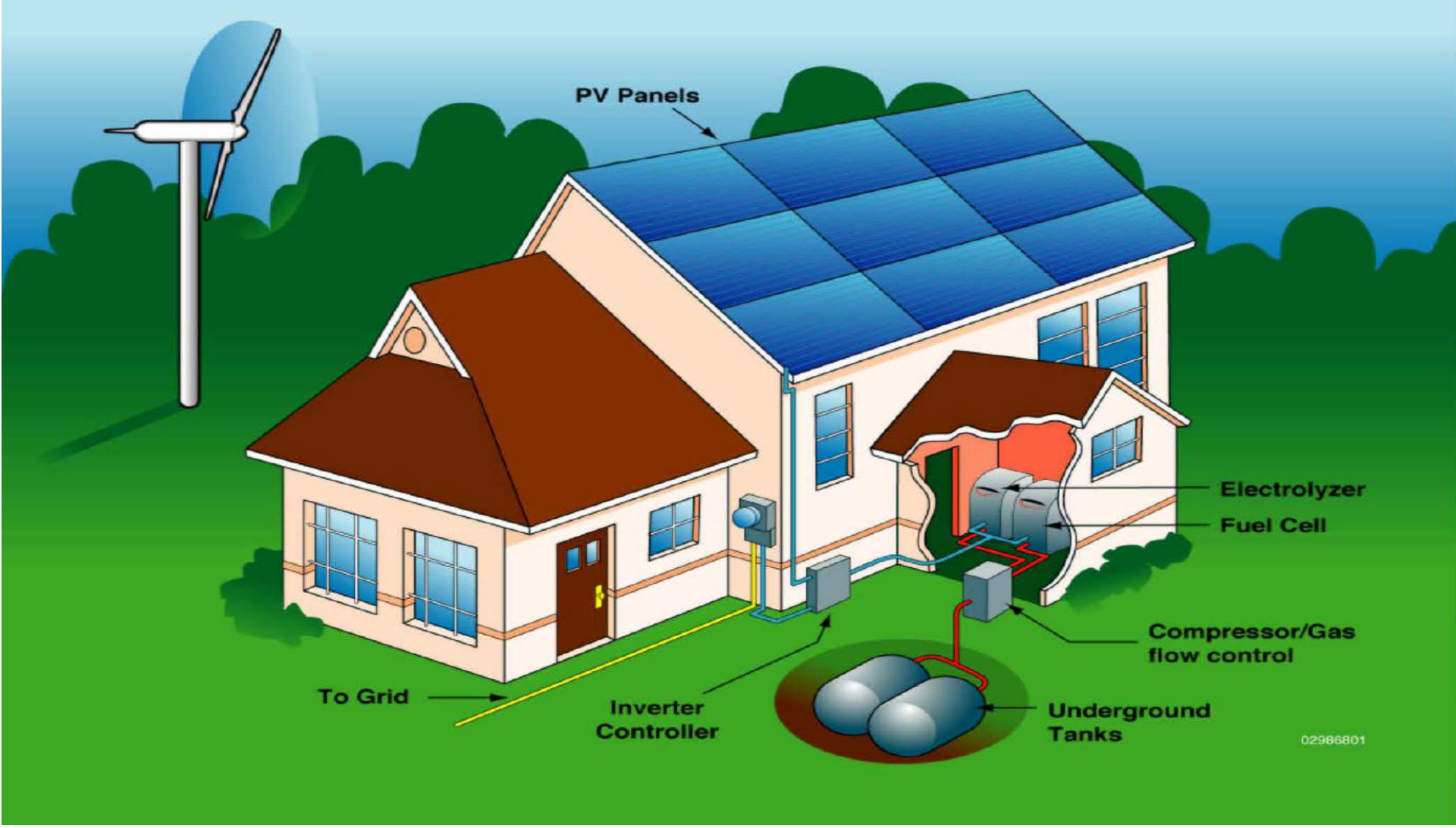
- R&D investments in Tier 1 schools must increase to make us competitive with high tech powerhouses EU, Japan, … and increasingly China.

- Example of successful partnership between Emerging Technology Fund of Texas, Texas Universities and Industry is the NRI South West Academy of Nanoelectronics at UT Austin, Dallas, Arlington, A&M & Rice:
  funded by Intel, IBM, TI, Micron, Global Foundries and NIST.

- The Bilayer Pseudospin Field Effect Transistor could consume 0.1% of the energy of conventional transistors if it can be made.

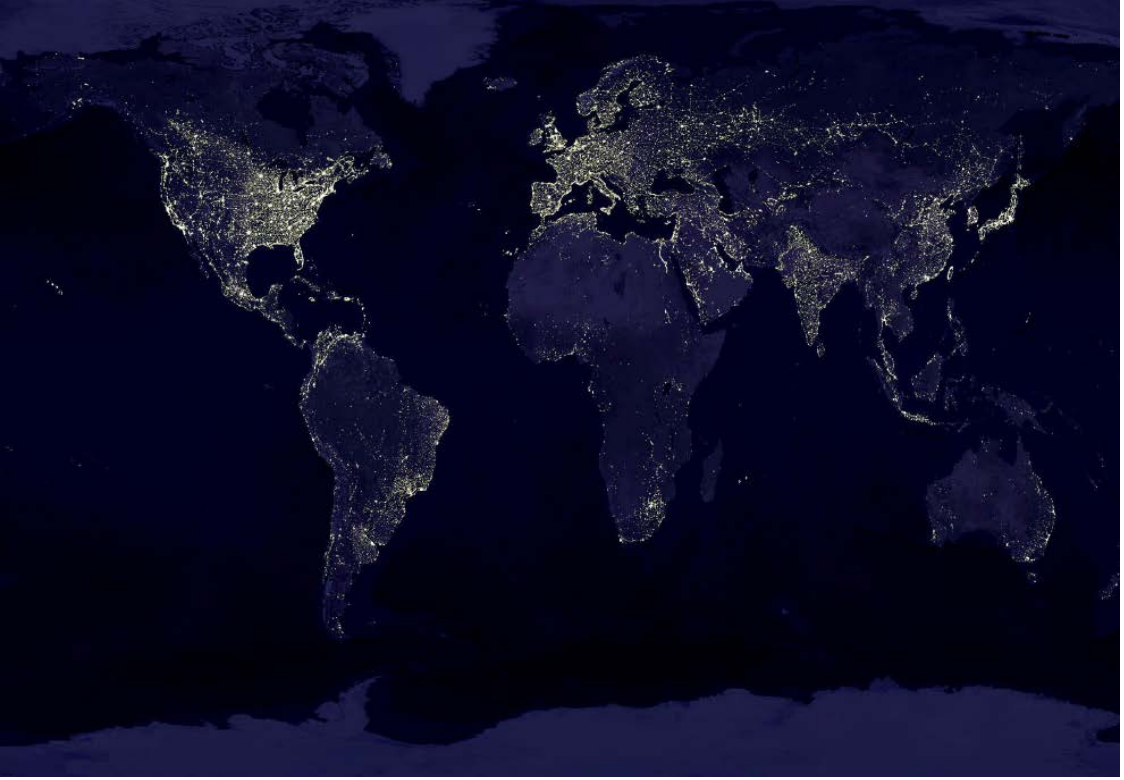





- Global energy demand is 15 TW (US ~3 TW), 5E20J; 50 TW by 2100

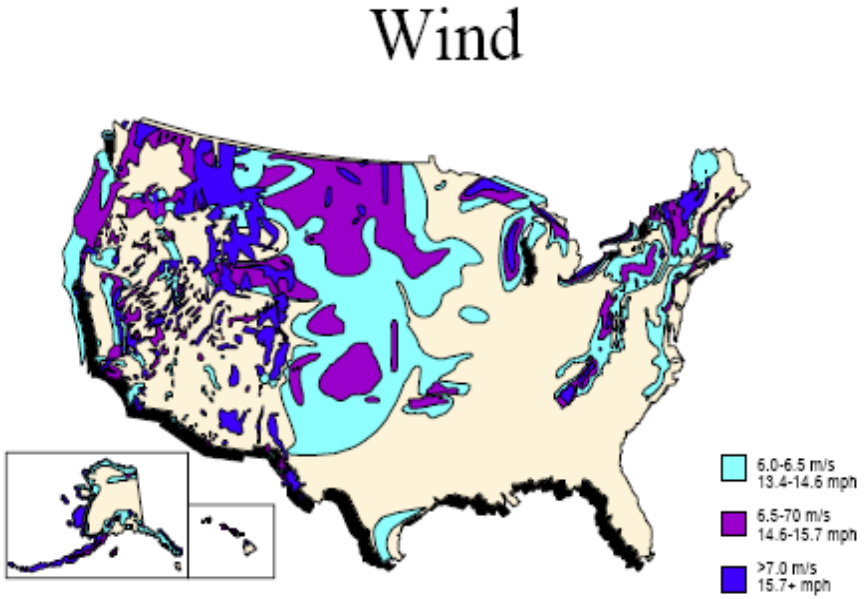
- Currently ~1 % of generation is solar and wind; rest from fossil fuels, hydro and nuclear. There is 5E24J of non-renewable fossil and nuclear fuel available.

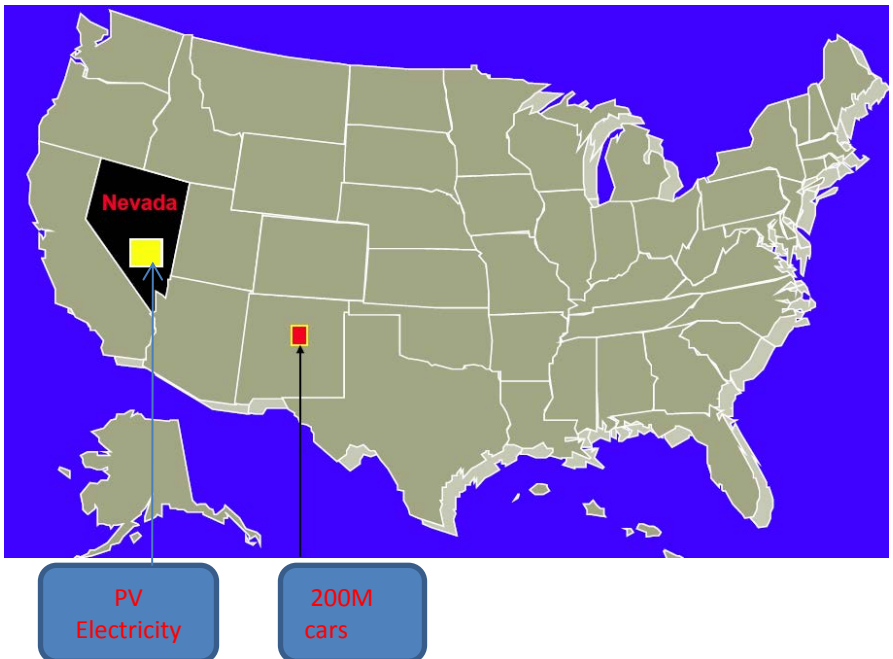


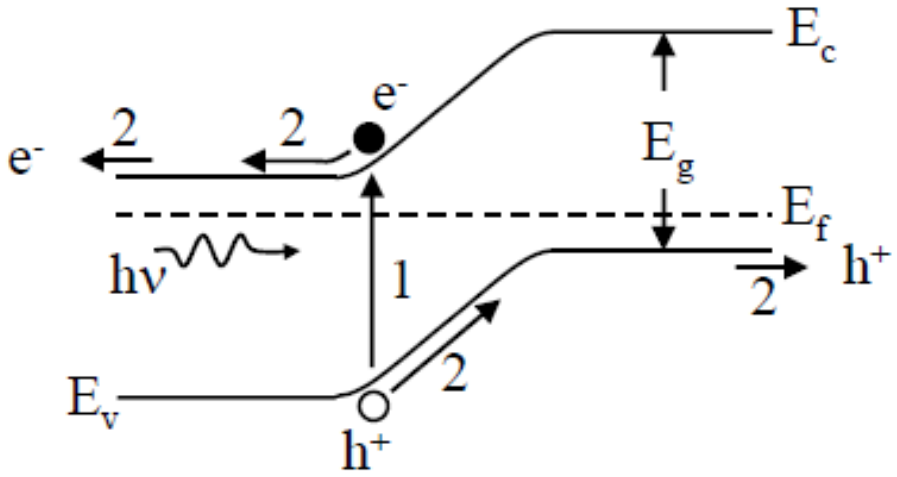
- There is 100,000 TW of solar power and 1700 TW of wind power; of this 6000 TW of solar and 100 TW of wind power are accessible. Total power is 8000 times current need.

- Solar and wind generation sites often far from cities- hence smart power grid critical

- Solar and wind suffer from intermittency problems- hence storage is critical





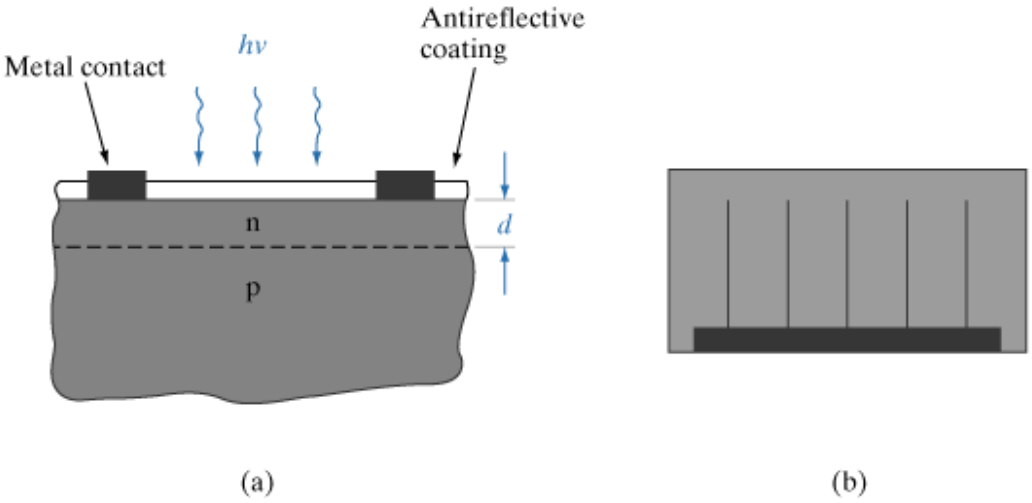
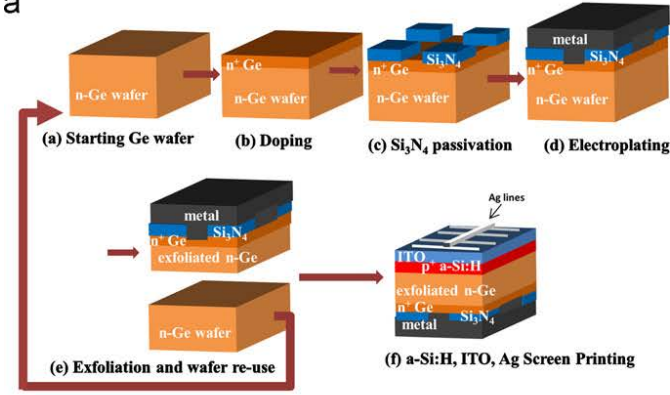
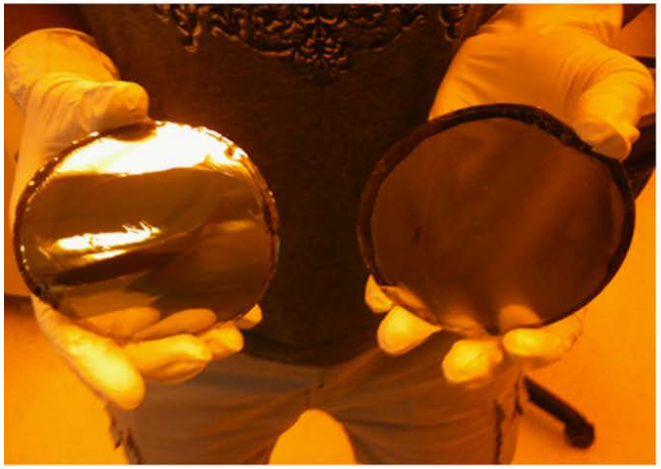




**Figure 8-5**
Configuration of a solar cell: (a) enlarged view of the planar junction; (b) top view, showing metal contact "fingers."

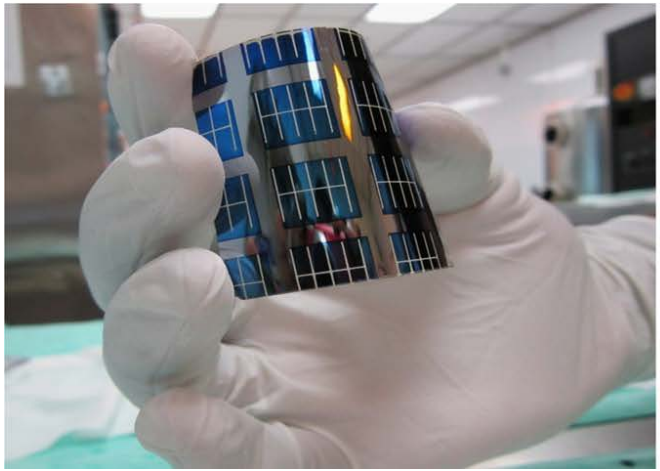
a

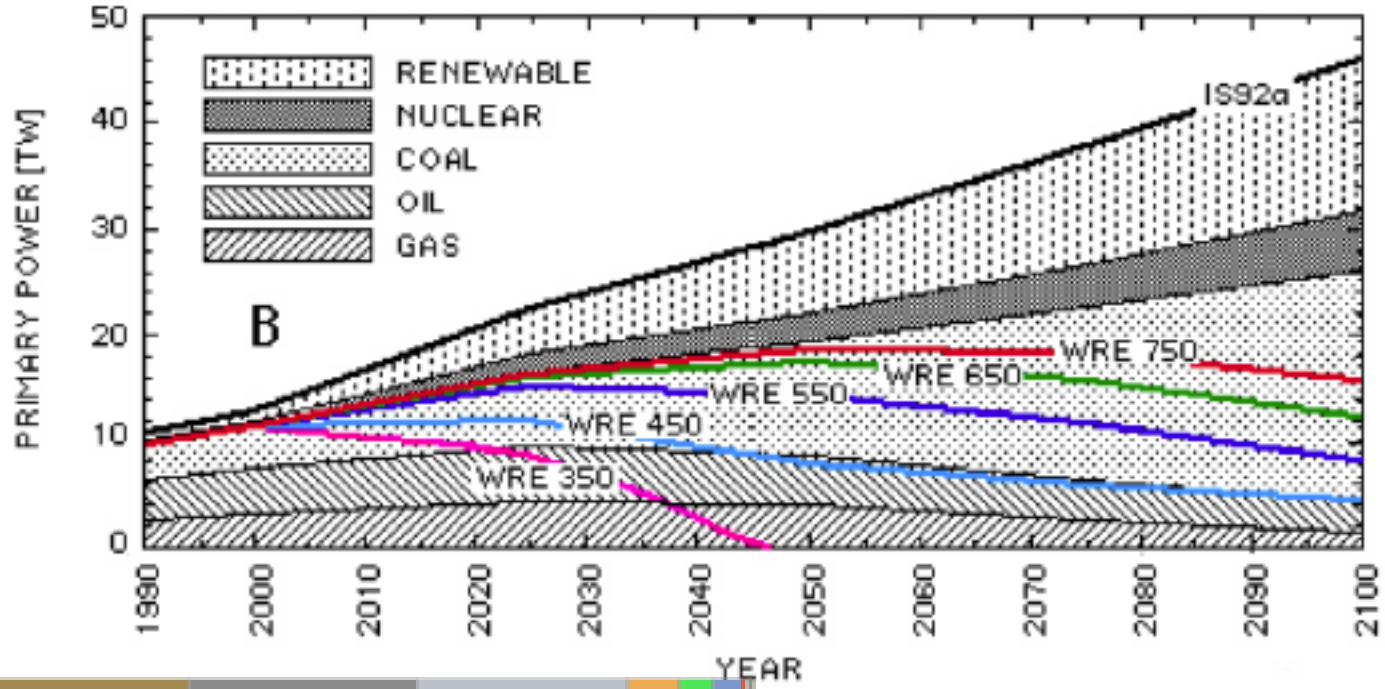


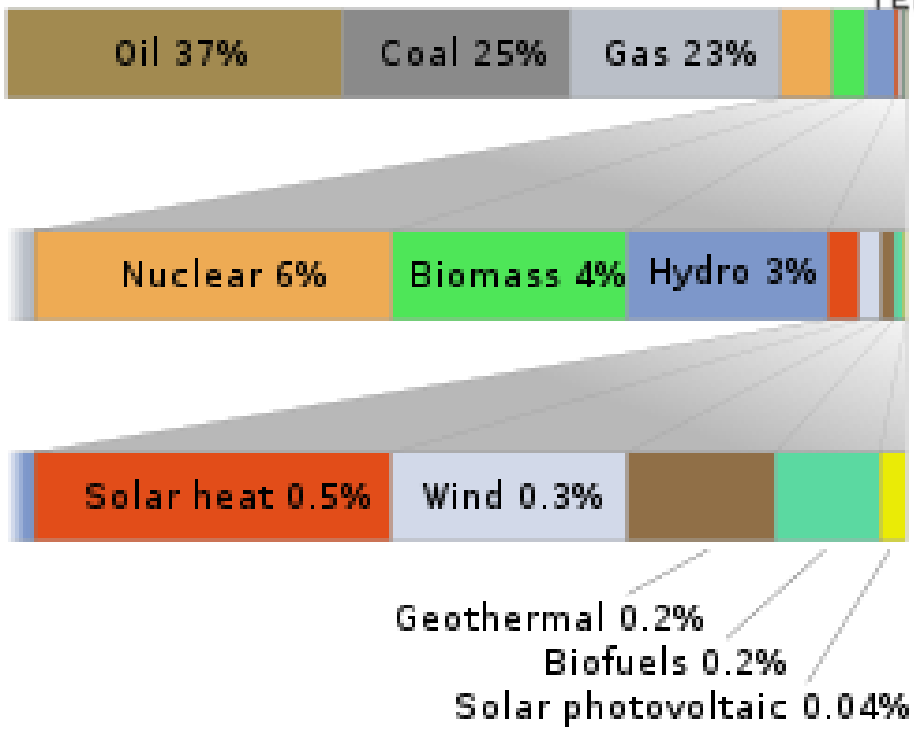

b

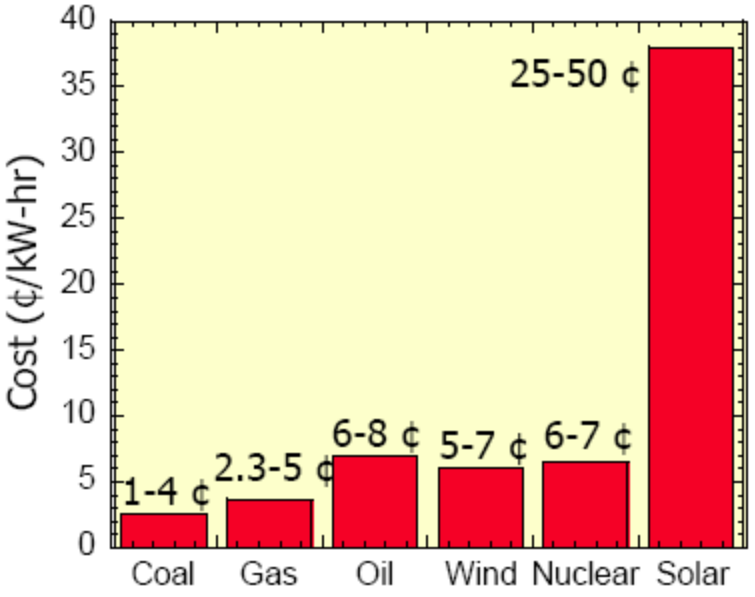


c

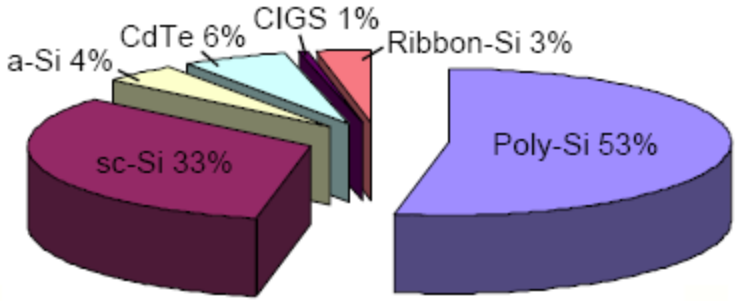



RENEWABLE
NUCLEAR
COAL
OIL
GAS
B
IS92a
WRE 750
WRE 650
WRE 550
WRE 450
WRE 350
PRIMARY POWER [TW]
YEAR
0
10
20
30
40
50
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100

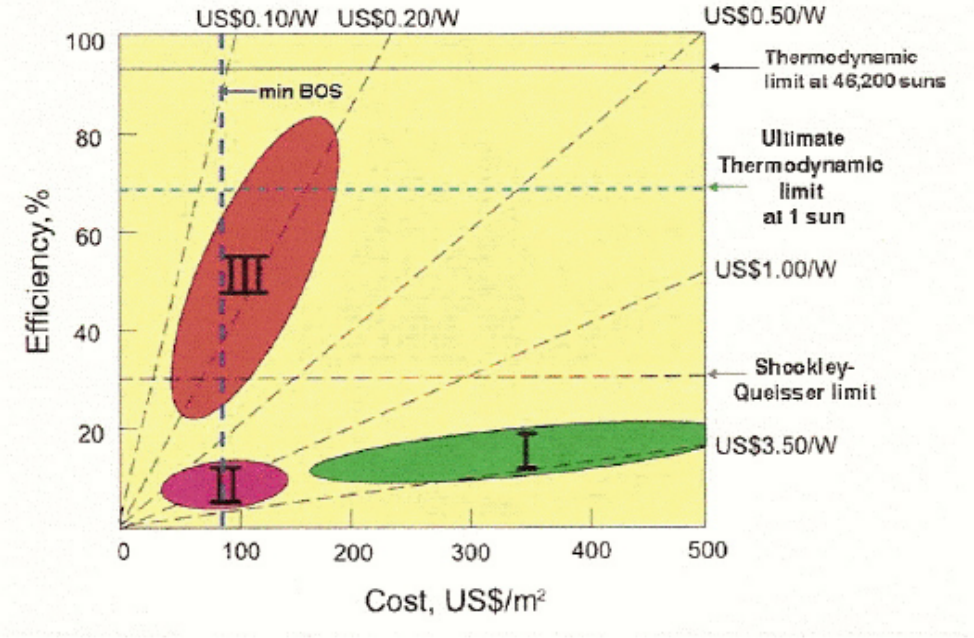

Oil 37%
Coal 25%
Gas 23%
Nuclear 6%
Biomass 4%
Hydro 3%
Solar heat 0.5%
Wind 0.3%
Geothermal 0.2%
Biofuels 0.2%
Solar photovoltaic 0.04%


Cost (¢/kW-hr)
0
5
10
15
20
25
30
35
40
1-4 ¢
2.3-5 ¢
6-8 ¢
5-7 ¢
6-7 ¢
25-50 ¢
Coal
Gas
Oil
Wind
Nuclear
Solar

# Industry Breakdown 2007



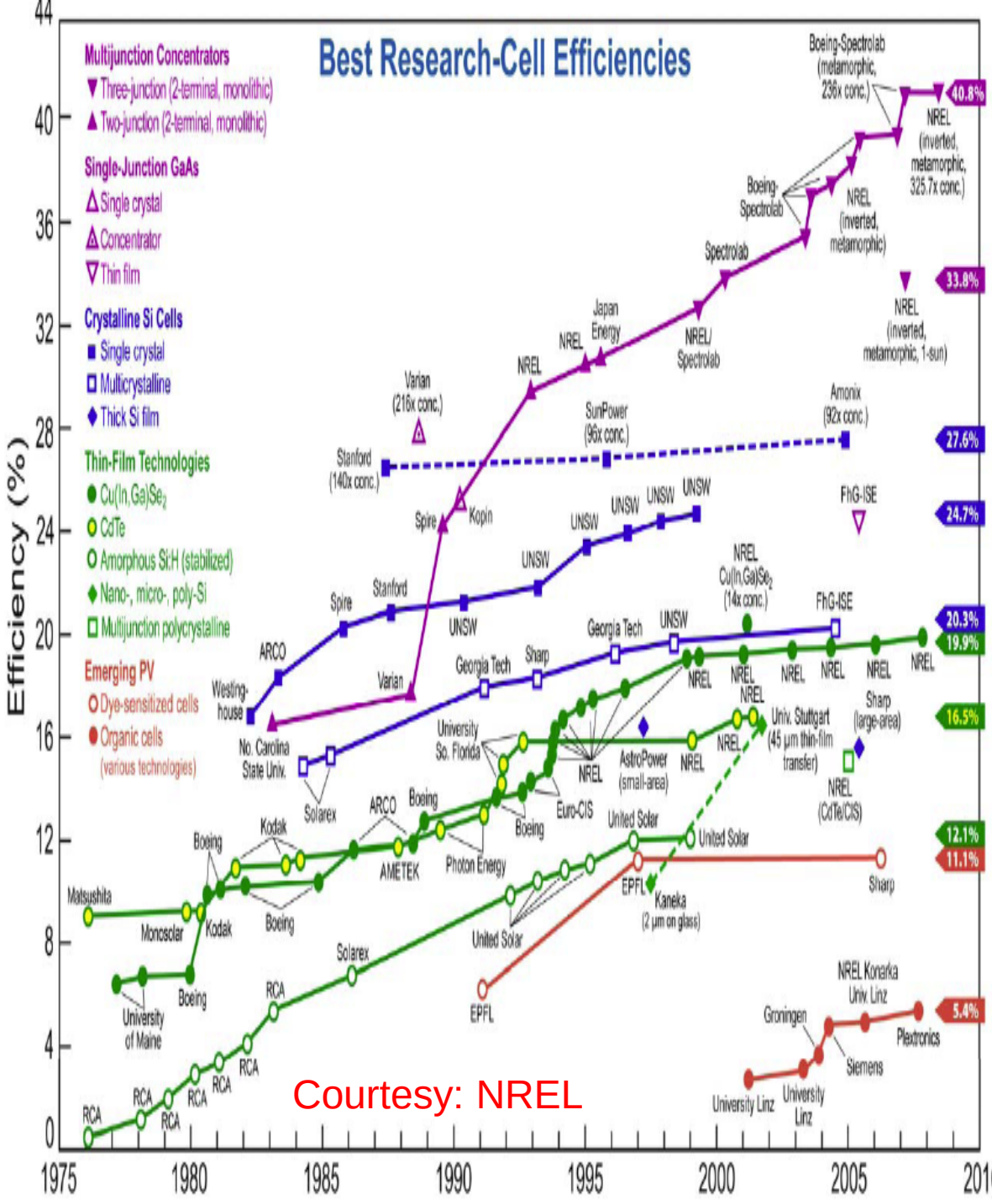

- Requirements
  - Efficiency ~50%
  - Cost ~\$0.20/$W_p$
- Currently
  - Efficiency ~15%
  - Cost ~\$3.50/$W_p$
- Improvement
  - Cost ~15X
  - Efficiency ~3X
  - FoM: Efficiency/Cost Ratio (%W/\$)



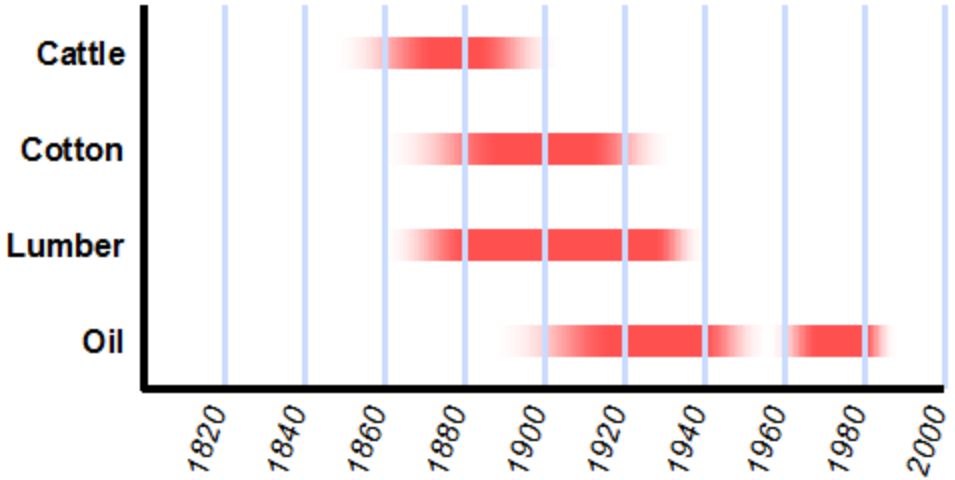

## 3rd Generation Solar Cells

As function of module efficiency and areal cost

M.A. Green, Third Generation Photovoltaics: Advanced Solar Energy Conversion (Springer, 2004).


Best Research-Cell Efficiencies
Multijunction Concentrators
Three-junction (2-terminal, monolithic)
Two-junction (2-terminal, monolithic)
Single-Junction GaAs
Single crystal
Concentrator
Thin film
Crystalline Si Cells
Single crystal
Multicrystalline
Thick Si film
Thin-Film Technologies
Cu(In,Ga)Se2
CdTe
Amorphous Si:H (stabilized)
Nano-, micro-, poly-Si
Multijunction polycrystalline
Emerging PV
Dye-sensitized cells
Organic cells
(various technologies)
Efficiency (%)
0
4
8
12
16
20
24
28
32
36
40
44
1975
1980
1985
1990
1995
2000
2005
2010
40.8%
33.8%
27.6%
24.7%
20.3%
19.9%
16.5%
12.1%
11.1%
5.4%
Boeing-Spectrolab (metamorphic, 236x conc.)
NREL (inverted, metamorphic, 325.7x conc.)
Boeing-Spectrolab
NREL (inverted, metamorphic)
Spectrolab
NREL (inverted, metamorphic, 1-sun)
Japan Energy
NREL
NREL/ Spectrolab
Varian (216x conc.)
SunPower (96x conc.)
Amonix (92x conc.)
Stanford (140x conc.)
Spire
Kopin
UNSW
FhG-ISE
NREL Cu(In,Ga)Se2 (14x conc.)
Spire
Stanford
ARCO
Georgia Tech
Sharp
Westing-house
Varian
No. Carolina State Univ.
Solarex
University So. Florida
AstroPower (small-area)
Univ. Stuttgart (45 μm thin-film transfer)
Sharp (large-area)
NREL (CdTe/CIS)
Euro-CIS
Kodak
Boeing
ARCO
AMETEK
Photon Energy
United Solar
Sharp
Matsushita
Monosolar
University of Maine
RCA
EPFL
Kaneka (2 μm on glass)
NREL Konarka Univ. Linz
Groningen
Plextronics
Siemens
University Linz
Courtesy: NREL

# Epilog: the 10 gallon economy in 2050



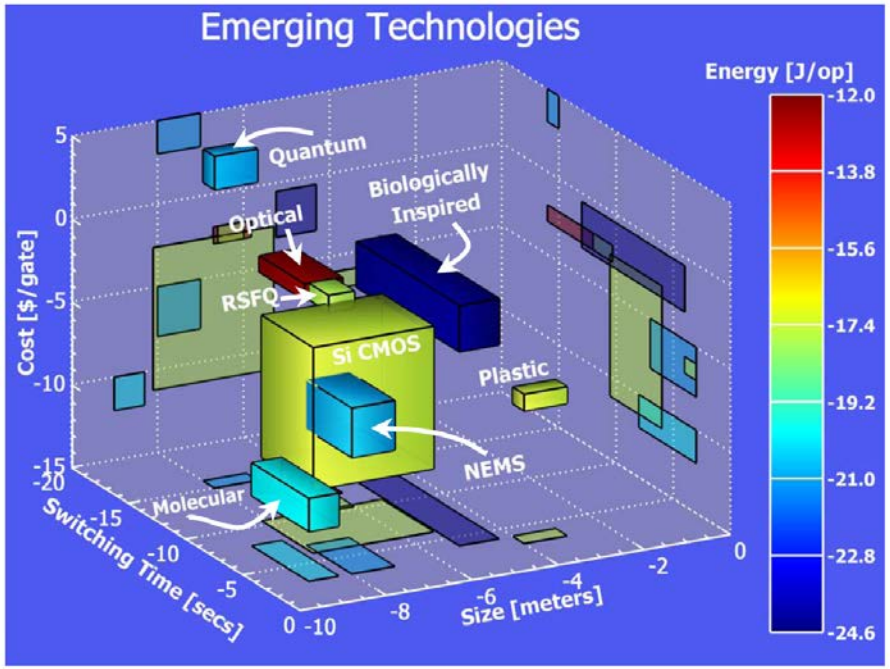




*Figure 42 Parameterization of Emerging Technologies and CMOS—Speed, Size, Cost, and Switching Energy*